

**\*\*FULL TITLE\*\***

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## Fourier Disentangling Using the Technology of Virtual Observatory

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**Abstract.** The Virtual Observatory is a new technology of the astronomical research allowing the seamless processing and analysis of a heterogeneous data obtained from a number of distributed data archives. It may also provide astronomical community with powerful computational and data processing on-line services replacing the custom scientific code run on user's computers.

Despite its benefits the VO technology has been still little exploited in stellar spectroscopy. As an example of possible evolution in this field we present an experimental web-based service for disentangling of spectra based on code KOREL. This code developed by P. Hadrava enables Fourier disentangling and line-strength photometry, i.e. simultaneous decomposition of spectra of multiple stars and solving for orbital parameters, line-profile variability or other physical parameters of observed objects.

We discuss the benefits of the service-oriented approach from the point of view of both developers and users and give examples of possible user-friendly implementation of spectra disentangling methods as a standard tools of Virtual Observatory.

### 1 Introduction

The astronomical spectroscopy uses many special techniques to analyse stellar spectra and estimate physical properties of targets studied. Basically they consist in comparison of the observed spectra with theoretical models which, however, may be of very different level of sophistication. For instance, a simple comparison of suitably defined effective centres of spectral lines with their laboratory wavelengths gives Doppler shifts, which in the case of spectroscopic binaries enables one to determine their orbital parameters. Detailed comparison of equivalent widths and shapes of line profiles with synthetic spectra may reveal effective temperatures, gravity acceleration, abundances and other physical parameters of stellar atmospheres. In practice, however, the spectra of components of the binary are blended and the information on orbital and atmospheric parameters are entangled.

Several techniques for separation of component spectra from a series of spectra has been proposed which enable also to develop the so called spectra disentangling, i.e. a method of simultaneous separation of the spectra and determination of physical parameters governing their variability. In particular, the method of Fourier disentangling introduced and implemented in program KOREL by Hadrava (1995) proved to be efficient and viable for a further generalisation.

To allow the application of such a powerful method on a number of different objects in a scalable way, we attempted to embed the KOREL in the infrastructure of Virtual Observatory.

## 2 The Virtual Observatory

Contemporary astronomy faces an enormous amount of data continuously flowing from large telescopes, space missions and supercomputer simulations, that can hardly be analysed (and even previewed) by the traditional scientific methods. Thus the concept of (astronomical) Virtual Observatory (VO) was recently born aiming at federalisation of all astronomical resources (e.g. catalogues, data archives, simulation databases, data processing and analysing tools) using the global infrastructure based on unified data format and set of rigid, yet extensible communication protocols. The development and implementation of these global standards is the role of the International Virtual Observatory Alliance (IVOA).

Technically, VO is a collection of inter-operating data archives and software tools which utilise the internet to form a virtual desktop environment in which astronomical research can be conducted in a user friendly manner allowing the astronomer to concentrate on asking the scientific questions instead of spending most of the time with searching in heterogeneous scattered archives, and with homogenisation of data represented by different units in various file formats.

Owing to its huge data-mining potential and easy multiwavelength analysis tools, the VO technology allows to tackle problems not feasible by any other means, like the search of very rare astronomical events, candidates of yet unknown classes of objects (e.g. extremely cold brown dwarfs, supermassive stars etc.), statistics of order of tens of millions target or pan-spectral classification as building the spectra energy distributions of radiation from gamma to radio using the archives of all space and ground-based observations together. For the extensive introduction into the VO science see Solano (2006).

## 3 The Fourier Disentangling

The disentangling of spectra represents nowadays a whole branch of stellar spectroscopy fairly exceeding the scope of our contribution. We thus refer for a detailed explanation of its physical and mathematical principles, astrophysical consequences and for corresponding literature to the review (Hadrava 2004) or its update (Hadrava 2009b). Here we shall only qualitatively characterise the method of Fourier disentangling implemented in code KOREL and we shall list a recent progress.

The instantaneous spectra of many variable objects can be in a good approximation expressed as a superposition of their intrinsic (time independent) components convolved with some broadening functions (e.g. Doppler shifted delta-functions) depending on time and some physical parameters of the variability (e.g. the orbital parameters). In the Fourier conjugate space the intrinsic components can thus easily be solved (independently for each Fourier mode) from a more numerous set of observations. Moreover, the values of the free parameters can be fit by the least-square method. To prevent an ill-determination

of the problem, a good coverage of the time interval of the characteristic variability is needed. The main task of the development of the method is thus to find a proper theoretical model of the broadening. Already the very simple assumption of line-strength variability with fixed line profiles (Hadrava 1997) enables many useful applications. To apply the method successfully to real data, the observers should understand the assumptions and properties of the model and to prepare a set of data decisive for the parameters required from the solution.

If the solution for the intrinsic component spectra is well over-determined by a great number of observed spectra, their noise can be substantially reduced by the averaging. A recent improvement of the numerical technique (Hadrava 2009a) enables to retrieve the radial-velocity shifts with an accuracy surpassing the limitations by the step of spectra sampling (this is sometimes called super-resolution). Our recent work (Hadrava et al. 2009) opens a disentangling of Cepheid pulsations.

## 4 The Virtual Observatory Web Services

As the Fourier disentangling of the large number of spectra may become computation intensive, its full power may be exploited using the modern technology of VO Web Services (WS). The WS is typically complex processing application using the web technology (http protocol and (X)HTML markup) to transfer input data (files, tables, images, spectra etc.) to the main processing back-end (often run in front of queue scheduling and/or parallelising engine on computer clusters or GRIDS) and the results (after intensive number crunching) back to user. All this can be done using only an ordinary web browser (and in principle the science may be done on the fast palmtop or advanced mobile phone).

The more detailed analysis about the benefits of GRID technology in stellar spectroscopy is presented by Škoda (2009). This service-oriented approach has many advantages both for the user and developer. Let's name some of them:

- There is the only one, current, well tested version of the code (and documentation), maintained and updated by its author
- The user needs not to install anything from the author
- The code is optimised for given HW (native compiler), knowing its limits (memory and cache sizes, number of nodes etc.)
- The problem is scalable - the more user requirements may be solved by adding more computing nodes and introducing priority queues
- The web technology provides the easy way of interaction (forms) and graphics output (in-line images) even produced dynamically (variable refresh rates or event driven - e.g. AJAX)

### 4.1 The KOREL Web Service

The idea of our service is to have an user interface similar to e-shop portal, starting with user registration. Every set of input parameters creates a job, which may be run in parallel with others, the user may stop or remove them, can

return to the previous versions etc. Privileged users may even recompile their own version of KOREL code tailored to their needs (e.g. maximum amount and size of spectra). All user communication is encrypted and the user can see only his/her jobs. The service may be accessed from the KOREL portal at Astronomical Institute in Ondřejov<sup>1</sup>.

At the time of preparation of the proceedings the KOREL Web Service requires to upload the files `korel.data` and `korel.par` in given strict format. Usually, for the preparation of input data the program PREKOR run at local computer is used, which reads spectra in various formats, rebins them equidistant in radial velocity (logarithmic wavelength) and optionally applies the precisely computed heliocentric correction. In addition to that, its interactive graphics helps to select the proper spectral regions bordered by the clear continuum and allows the removal of bad spectra.

In the future, the role of the PREKOR may be replaced by another set of web services acquiring the spectra directly from VO servers and using proper metadata (e.g. elements of orbits) obtained from proper catalogues published in VO (especially CDS VizieR and Simbad). The interactive capability will be provided by VO spectral tools (e.g. SPLAT or VOSpec).

## 5 Conclusions

The Fourier disentangling is already well-established method of stellar spectra analysis with the wide range of applications. The KOREL web service is probably one of the first attempts to adapt the legacy stellar spectra analysis code for the Virtual Observatory service. The advantages of solution adopted are evident, although some level of user conservatism has to be expected.

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<sup>1</sup> <http://stelweb.asu.cas.cz/vo-korel>